ACHIEVEMENTS IN MINE SAFETY RESEARCH AND PROBLEMS YET TO BE SOLVED

BY ARNO C. FIELDNER

* * * * * * * * * *

Information Circular 7573

UNITED STATES DEPARTMENT OF THE INTERIOR
Oscar L. Chapman, Secretary
BUREAU OF MINES
James Boyd, Director

Work on manuscript completed June 1950 . The Bureau of Mines will welcome reprinting of this paper, provided the following footnote acknowledgment is made: "Reprinted from Bureau of Mines Information Circular 7573."

Paper presented at the Sixth International Conference of Directors of Safety in Mines Research at the laboratories of the Centre D'Etudes et de Recherches des Charbonnages de France, Verneuil, France, July 24 to 29, 1950.

June 1950

Generated on 2024-09-19 22:15 GMT / https://hdl.handle.net/2027/osu.32435030643720
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google

Digitized by Google

Original from
THE OHIO STATE UNIVERSITY

ACHIEVEMENTS IN MINE SAFETY RESEARCH AND PROBLEMS YET TO BE SOLVED

by

Arno C. Fieldner[1/]

CONTENTS

	Page
Introduction	1
Review of progress in mine safety research from 1910 to 1950	3
Permissible explosives and their use	3
Dust explosions	5
Gas explosions	7
Ventilation, mine air, and air-borne dust	8
Oxygen breathing apparatus, respirators, and gas masks	14
Electrical and mechanical equipment	16
Electric lamps	17
Telephones and signaling devices	17
Blasting devices	18
Diesel locomotive and Diesel-powered mobile equipment	18
Equipment for mechanized mining	19
Prevention of roof falls	20
Problems yet to be solved in mine safety research	21
Explosives and their use	21
Dust explosions	22
Gas explosions	23
Ventilation, mine air, and air-borne dust	25
Oxygen breathing apparatus, respirators, and gas masks	26
Electrical and mechanical equipment	27
Prevention of roof falls	28
Summary	29
Acknowledgments	31

1/ Chief, Fuels and Explosives Division, Bureau of Mines, Washington, D. C.

Information Circular 7573

Generated on 2024-09-19 22:20 GMT / https://hdl.handle.net/2027/osu.32435030643720
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from THE OHIO STATE UNIVERSITY

INTRODUCTION

Forty years have elapsed since the Bureau of Mines was established on July 1, 1910, by Act of Congress. The convocation of this Sixth International Conference of Safety in Mines Research Directors, 24 days after our 40th birthday, seems to be an appropriate time for reviewing our contributions to mine safety research and the problems yet to be solved from the American point of view.

Actually research on safety in coal mines was started by the United States Government in the Technologic Branch of the U. S. Geological Survey of the Department of the Interior in 1908, as a result of a succession of disastrous coal mine explosions in which many lives were lost. In 1910 this work was transferred to the newly created Bureau of Mines.

394 lives were lost annually per 100,000 men employed in the coal mines of the United States in the 5-year period ended in 1910, as compared to 203 lives lost annually in the 5-year period ended with 1949.

In 1908 no safe, permissible types of explosives and no certified permissible equipment of any kind were used in American coal mines. Black powder was in universal use and open oil or acetylene lights were common in all but mines known to be gassy. Rock dusting was not practiced to limit propagation of explosions, nor was ventilation in many mines adequate.

Our safety practice lagged behind that of foreign coal-mining countries and therefore one of the first steps in carrying out the Congressional Authorization of 1908 to investigate the causes of mine explosions was to obtain assistance from the leaders of mine safety research in foreign countries. At the request of Dr. Joseph H. Holmes, director of the Technologic Branch of the Geological Survey, James R. Garfield, Secretary of the Interior, obtained the cooperation of the Governments of England, Belgium and Germany in sending Captain Arthur Desborough, Inspector of Explosives in England, Mr. Victor Watteyne, Inspector-General of Mines in Belgium, and Mr. Carl Meissner, Counselor for Mines in Germany, to visit American mines and make recommendations for increasing safety and efficiency in mining coal in the United States.

These experts accompanied by Dr. Holmes visited representative mines in the United States and in October 1908 submitted a report2/ to

---

2/ The prevention of mine explosions. Report and recommendations: Bureau of Mines Technical Paper 21, 1912, 12 pp. (Reprint of U. S. Geological Survey Bull. 369, 1908) by Victor Watteyne, Carl Meissner, and Arthur Desborough.

Generated on 2024-09-19 22:15 GMT / https://hdl.handle.net/2027/osu.32435030643720
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from THE OHIO STATE UNIVERSITY

the Secretary of the Interior recommending a program of continuous research and development to improve safety and of educational work with the operators and miners to adopt safer methods and equipment.

Valuable advice also was obtained from J. Taffanel, Director of the Lievin Experiment Station in France, especially with respect to limiting dust explosions. These recommendations were well received by American coal operators and formed the basis of the safety program initiated in 1908. By 1910, when the Bureau of Mines was created by Congress, an excellent staff was at work and the following projects were under way:

(a) The installation of equipment for testing explosives similar to that used in European testing stations, and the certification as permissible of a number of short-flame American explosives that had been developed by manufacturers.

(b) Operation of an electrical investigations section for developing permissibility requirements for electrical equipment, safety lamps, and electrical types of methane indicators.

(c) Investigation of the occurrence of methane in American coal mines and the adequacy of ventilation to prevent the accumulation of dangerous concentrations.

(d) Laboratory research on the flammability of coal dust and the quenching of flame by the presence of stone dust.

(e) Planning of an experimental coal mine at Bruceton, near Pittsburgh, Pennsylvania, to study the prevention of ignition and propagation of coal dust explosions, and

(f) Investigation of foreign mine rescue methods and equipment and their adaptation to American conditions.

These operations of the Bureau of Mines in its first year constituted an excellent beginning in a virtually uncultivated field of safety research pertaining to American coal mines. Let us see what has been accomplished in the 40 years since 1910. For this review the various fields of safety-in-mines research are subdivided as follows: (1) explosives, (2) dust explosions, (3) gas explosions, (4) ventilation, mine air, and air-borne dust, (5) oxygen breathing apparatus, respirators, and gas masks, (6) electrical and mechanical equipment, and (7) prevention of roof falls.

Generated on 2024-09-19 22:14 GMT / https://hdl.handle.net/2027/osu.32435030643720
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from THE OHIO STATE UNIVERSITY

REVIEW OF PROGRESS IN MINE SAFETY RESEARCH FROM 1910 to 1950

Permissible Explosives and Their Use

The first list of permissible explosives was published May 15, 1909. In the approximately 41 years of test work since that time, a total of 767 explosives have been tested for permissibility and 475 of these have been certified as permissible. At present 191 explosives are on the active list, the rest of the certified brands being on the inactive list.

Although permissible explosives have established an impressive safety record, adoption of these safer blasting agents has been relatively gradual. In 1926, only 25 percent of all explosives used in coal mines were permissible. In 1949, however, black powder constituted but 16 percent of the blasting powder used in American coal mines.

Since inauguration of the explosives testing program, there has not been a coal mine explosion definitely chargeable to permissible explosives when such explosives were used in a permissible manner. It is noteworthy that these results have been obtained without any material loss in blasting efficiency. Thus, permissible explosives have been developed by American industry that do not generally require large amounts of inert diluents or inert sheaths to prevent initiation of an explosion even in gassy or dusty mines. The use of these relatively strong permissible explosives has materially aided in maintaining the coal production rate demanded in the United States.

The gallery tests are still considered the most basic part of our test program. These tests are similar to those made by many other stations and consist in firing the explosive in a cannon that discharges into a gallery filled with either an 8 percent natural gas-air mixture or a 4 percent natural gas-air mixture with coal dust.

In addition to the gallery tests, every permissible explosive must pass rigid tests to determine its sensitiveness to frictional impact, direct impact, and propagation of the explosive wave. Chemical analysis of the explosive and of the gaseous products of the explosion are an integral part of the tests.

The Bureau of Mines periodically collects and tests samples of all permissible explosives on the active list. If the field sample fails to pass the prescribed tests, immediate action is taken to make the explosive meet the permissibility limits. This method of field sampling has proved very satisfactory in keeping permissible explosives within closely defined limits.

It should be remembered that when the original tests on explosives were developed, very little was known of the mechanism of the ignition of methane-air mixtures. As an understanding of this mechanism is fundamental to the program of safety in coal mines, the Bureau has considered investigation of this mechanism as one of its

Generated on 2024-09-19 22:15 GMT / https://hdl.handle.net/2027/osu.32435030643720
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from THE OHIO STATE UNIVERSITY

most fundamental research problems. The first workers on this problem approached it as a flame study, based upon the belief that the longer the flame and the longer the time it endures, the greater is the chance that such a flame will ignite inflammable mixtures of gas and air. Photographic records were obtained with ordinary stationary cameras, and the data so obtained demonstrated the vast difference between flames from black powder and from permissible type explosives. However, the photographic equipment and technique did not permit general solution of the fundamental problem.

During the late 1920's, considerable progress was made both in our laboratories and in other interested laboratories on problems related to the fundamental mechanism of the ignition of gas-air mixtures. Not only were the fundamental processes studied, but also characteristics of the explosion process, such as the shock wave, gaseous products, type of flames involved, and nature of the ejected particles.

Since the last war the problem of the ignition mechanism has been attacked with renewed vigor. A theory has been advanced by Bureau personnel that the sensitivity of gas-air mixtures may be associated with the presence of pockets of unburned gas surrounded by products of combustion. Such pockets are physically possible and have been found experimentally. Recent investigations in our laboratories tend to verify the presence of such local centers of combustion in the pocketed volume. A more complete discussion of this work is given in a paper being presented to this conference. The program of investigation at our laboratories is thus yielding interesting results and we have reason to hope that much more fundamental information will be available in the foreseeable future.

During the first 35 years of the use of permissible explosives in American coal mines, even a certified explosive was not considered permissible if more than 1-1/2 pounds of it were used per shot hole. In 1943, the Coal Mining Institute of America recommended to the Director of the Bureau of Mines that the charge limit for permissible explosives be increased from 1.5 to 3 pounds per shot hole. The coal mining industry was generally unanimous in its desire for this increase in charge limit to satisfy the higher production schedules desired for the war period. In January 1945, the Bureau tentatively approved the increase in charge limit, and this tentative approval was made permanent in January 1948, after an extended series of more than 650 tests in the Experimental Coal Mine at Bruceton, Pa. Thus, a marked spur was given production without sacrifice of safety.

Continuous search for safer, cheaper, and more efficient methods of coal breakage has led American industry to a number of recognized substitutes for fixed explosives. One of these blasting devices, Cardox, has a potential ignition hazard associated with the heating element employed. The Bureau of Mines tests and approves devices of this character. The greatly expanding use of such devices warrants increasing interest and study in the use of these blasting methods.

Generated on 2024-09-19 22:15 GMT / https://hdl.handle.net/2027/osu.32435030643720
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from THE OHIO STATE UNIVERSITY

Although the original test methods installed at the Explosives Testing Station have generally proved very satisfactory, it is only to be expected that new and better methods can and should be developed as a better understanding of fundamental processes unfolds. A brief description of one or two of the more recent developments illustrating possibilities will be discussed later in this paper under the heading of problems yet to be solved.

Dust Explosions

The Experimental coal mine of the Bureau of Mines completed at Bruceton, Pa., in 1911, was the first underground explosion testing gallery in the world simulating actual coal mine conditions, although surface testing galleries had been in use in England and European countries for several years prior to the beginning of the Bureau of Mines investigations. The principal objectives of the mine work were the study of the initiation and development of coal mine explosions and of measures for preventing or limiting them. The need for such work was great, because factual data concerning explosions were very limited, especially with regard to the role played by coal dust.

It had been known for a long time that finely divided coal dust takes part in many explosions, but 40 years ago few people in America believed that in the absence of methane in the mine air, coal dust in suspension could be ignited and could produce violent and widespread explosions under actual mining conditions.

One of the first tasks undertaken in the Experimental mine was to disprove this misconception. In 1910 and for some time thereafter many mining people thought that moist coal dust or dust in a humid mine could not be exploded. Several investigations with bituminous and subbituminous coal dusts have shown conclusively that when moist dust is thrown into suspension, as by a localized gas explosion, it can be ignited and can readily propagate an explosion. This fact was also illustrated in a number of severe coal dust explosions in "wet" mines.

To date over 2,000 large-scale explosion tests have been conducted in the Experimental mine under widely varying, carefully controlled conditions. In these tests measurements were made of the velocity and length of the explosion flames, velocity of the pressure wave in advance of the flame, rise and fall of the pressure at various points in the course of the explosion, composition of the gases at various stages of an explosion, composition of coke and ash residues, and other physical and chemical phenomena associated with the explosions.

It was determined that the following factors exert an important influence on dust explosions in coal mines: (1) size of dust, (2) composition of dust, (3) quantity of dust, (4) distribution of dust, (5) flammable gas in air, (6) source of ignition, and (7) surrounding conditions, including geometry of the mine passageways and character of the rock surfaces therein.

Many tests were performed with pure coal dust from various parts of the United States; in other tests mixtures of coal dust and limestone dust, shale, salt, and other inert rock dusts were used.

Generated on 2024-09-19 22:14 GMT / https://hdl.handle.net/2027/osu.32435030643720
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from THE OHIO STATE UNIVERSITY

It was learned that coal dust as coarse as 20 mesh may take part in the combustion in mine explosions, but that the fine particles in the dust control the ease of ignition and the speed of flame propagation. Coal dusts containing high percentage of combustible volatile matter were found to be the most explosive, but dusts with only 10 or 12 percent volatile matter can and have been exploded. The tests showed the ineffectiveness of so-called dustless zones in a dry coal mine and of watered or wet zones in stopping an explosion. It was determined that a dust explosion can be propagated in the presence of very small amounts of coal dust, 0.05 ounce or more per cubic foot of air space (50 gms. per cu. meter). The presence of small percentages of flammable gas was found to enhance the ease of ignition of coal dust and to make it more difficult to stop the explosions. Explosions initiated by strong igniting sources were found to develop much faster and to produce more violence than those initiated by a weak source. Recent work has shown that coal dust explosions can be initiated without difficulty in comparatively wide and short connected rooms as well as in long narrow entries.

Much effort was directed toward the development of measures to prevent the propagation of coal dust explosions. This research was greatly instrumental in proving to the American mining men that generalized rock dusting is effective in stopping explosions, and this system of protection has been widely adopted in bituminous and in lignite coal mines.

The rock dust requirements were determined for many coal fields by large-scale tests in the mine or later in small-scale laboratory studies. On the basis of the mine tests it has been recommended that all passageways in producing entries in mines should be rock dusted to within 40 feet (12.2 meters) of the coal face. For initial application, a minimum of 3 to 4 pounds of rock dust per linear foot (4500 to 6000 gms. per meter) of entry is recommended, and frequent reexamination and redusting are necessary.

Experimental studies have shown that explosion flames can be checked or extinguished by installing of properly designed rock dust barriers in mine passageways. Owing partly to the work needed to maintain barriers in good operating condition at all times and to the rapid advance of the mine workings, rock dust barriers have not come into wide use in the United States.

Research on various measures for trapping dust at its source of production and on allaying dust on mine roadways has also contributed to the reduction of the explosion hazard. Other studies were directed toward the prevention and control of coal mine fires, which frequently cause or are the result of mine explosions. Studies of the igniting hazards of open lights, electric sparks, nonpermissible explosives, and other agents and practices commonly encountered in "nongassy" but dusty coal mines, and the introduction of permissible lights, machinery, explosives and other devices have likewise prevented many explosions.

Generated on 2024-09-19 22:19 GMT / https://hdl.handle.net/2027/osu.32435030643720
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from THE OHIO STATE UNIVERSITY

The various investigations in the Bureau's experimental mine together with the results of similar and other studies made in testing galleries of England and European countries, have greatly increased our understanding and control of coal dust explosions, and the results are gratifying if we compare the record within recent years with statistics of 30 or 40 years ago.

Gas Explosions

Great progress has been made during the last 40 years on the causes and prevention of gas explosions. At the start of this period little was known about the explosive properties of combustible gases found in mines before and after explosions. These problems were investigated in the laboratories of various countries and rather exact information is now available on the limits of flammability, ignition temperatures, flame speeds and pressures developed on explosion of the various combustible gases encountered in mining and industrial operations.

Comprehensive knowledge has been obtained concerning the mode of occurrence of firedamp in mines, its liberation during mining, and the conditions under which flammable atmospheres may exist. The ignition of these combustible atmospheres by open flames, heated materials, unsafe electrical equipment and by materials subject to spontaneous oxidation have been studied.

By means of the information now available it is possible to prevent many explosions and fires in mines by adopting preventative measures such as (1) provision of adequate ventilation in all parts of the mine including the working faces, so as to maintain the combustible gas concentration below the lower limit of flammability, (2) use of permissible mining equipment, and (3) use of permissible explosives.

Sealing mine fire areas to extinguish fires always involves the risk of explosion. To prevent such explosions it is necessary to reduce the oxygen content of the atmosphere quickly to the point where the flame will not propagate, and to do so before the combustible gases liberated by the coal and fire reach concentrations equal to or above the lower limit of flammability. Information relative to the explosibility of mine gases in atmospheres deficient in oxygen is now available and the explosion hazards of sealed areas can be determined by sampling and analyzing the atmosphere from the area. Thus, mine management can employ safe procedures to control and extinguish fires in mines and tunnels and prevent explosions when dealing with complex combustible gas mixtures in general.

The explosive properties of a large number of industrially important combustible gases and vapors and the relationships between combustible present and oxygen content of the atmospheres in order to keep outside the explosive range have been determined. Thus it is now possible to prevent explosions by the application of inert gases such as carbon dioxide, nitrogen, helium, freon, carbon tetrachloride, and similar halogenated gases or vapors. The amount of the given inerts required to be added to prevent explosions depends on the

Generated on 2024-09-19 22:16 GMT / https://hdl.handle.net/2027/osu.32435030643720
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from THE OHIO STATE UNIVERSITY

nature and amount of combustible gases present and the particular inert gas added.

Helium has been found useful as a flame quenching agent in rendering non-explosive combustible anesthetic mixtures used in hospital operation rooms.

Dangers from the leakage of odorless combustible gases, such as natural and liquefied petroleum gases from underground gas systems have been mitigated by the introduction of highly odorous warning agents of the mercaptan type into the piping system.

A method has been devised for detecting highly reactive carbides. Certain carbides in contact with moisture-laden acetylene heat to excessively high temperatures, in some cases sufficiently high to ignite and explode the acetylene if the pressure is above a certain amount, depending on the percentage of water vapor present. Methods have been worked out whereby acetylene gas may be stabilized by the introduction of moderate amounts of hydrocarbons such as methane, natural gas, propane, or butane.

Explosions in underground spaces, such as sewers and manholes, have been greatly reduced in number by systematic testing of the underground atmospheres. The composition and amounts of combustibles in the underground spaces are determined and if necessary, corrective measures are taken. The origin of such atmospheres may be leaking gas mains, volatile combustible liquids, electrolysis, or bacterial action on organic matter in the spaces. The causes of possible explosions are then eliminated by removing the source of the contamination, the ignition sources, or in special cases by providing ventilation in the enclosed areas. Systematic surveys of manholes in underground conduits of several cities in the United States, extending over a number of years, have shown that the presence of combustible gases can be virtually eliminated and the occurrence of explosions reduced accordingly.

Ventilation, Mine Air and Air-borne Dust

In 1910, though a considerable amount of engineering knowledge was available, coal-mine ventilation was almost entirely on an empirical trial-and-error basis. Throughout the years there has been a very considerable increase in the amount and reliability of engineering data made available, and the practice of ventilating coal mines has been greatly improved because of the necessity of maintaining the concentration of methane far below the lower explosive limit.

In metal mine ventilation methane is seldom encountered but adequate ventilation must be maintained to remove toxic fumes from blasting and to maintain comfortable working conditions.

The part the Bureau of Mines has played in mine and tunnel ventilation research is given in a recently published Information Circular - No. 7556, "Historical Resume of Mine and Tunnel Ventilation

Generated on 2024-09-19 22:17 GMT / https://hdl.handle.net/2027/osu.32435030643720
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from THE OHIO STATE UNIVERSITY

Studies, Bureau of Mines, 1910-1949", April 1950. High lights in these studies have been:

(1) Field studies of underground air conditions in metal mines in cooperation with companies have furnished information on the composition of blasting gas, occurrence of irrespirable strata gases, use of special auxiliary fans, underground temperatures and other factors for establishing practical standards for the health and comfort of underground workers. Some of the studies were concerned not only with the determination of empirical factors for flow of air through typical metal-mine airways and both rigid and flexible tubing, but also with methods of air measurement, operation and testing of fans, natural-draft effects, air-temperature changes, and other relevant factors.

(2) A study of comparative comfort conditions as determined by air temperature, humidity, and motion, was carried out at the Bureau's Pittsburgh laboratories over the period 1922-1927 in cooperation with the Research Laboratory of the American Society of Heating and Ventilating Engineers and the Public Health Service. This study resulted in the formulation of a new concept - effective temperature - for expressing the interrelation of air temperature, humidity, and movement on sensations of bodily comfort.

(3) Studies are now in progress on the application of mechanical air-cooling to deep metal mines, for which purpose an all-pressure psychrometric chart, something not previously available, was developed to facilitate determinations of change of heat and moisture content of air flowing through mine openings.

(4) The Bureau of Mines pioneering study of vehicular tunnel ventilation led to the adoption of the transverse method used in the Holland vehicular tunnel in New York City. This method is now used for many important vehicular tunnels. The intrinsic safety of this method over methods of longitudinal ventilation was demonstrated May 13, 1949, when a truck loaded with very flammable carbon disulfide burned in the Holland tunnel. What might have been a major calamity became instead a serious accident and no lives were lost.

The Bureau's study involved determinations of the amount and composition of exhaust gases from motor vehicles, of the physiological effects of exhaust gases, of empirical factors for calculating pressure and power requirements, and of the relative merits of various proposed methods of transverse ventilation. The latter tests were carried out in a 400-foot, continuous, oval-shaped tunnel constructed to scale in the Bureau's Experimental Mine at Bruceton, Pa. Up to 10 small passenger cars were operated at one time in this tunnel, and the tests required the services of up to 50 men.

(5) The coal-mine ventilation studies of the Bureau have been conducted in close cooperation with the companies. Ever since the establishment of the Bureau, samples have been taken of mine air and the operators advised if ventilation was inadequate. A

Generated on 2024-09-19 22:17 GMT / https://hdl.handle.net/2027/osu.32435030643720
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from THE OHIO STATE UNIVERSITY

study to determine empirical factors required for calculating the pressure requirements for flow of air through typical coal-mine airways, carried out in the Experimental Mine and Indiana coal mines, has been helpful to fan manufacturers and operators in designing fans and airways.

Gas analysis and detection of flammable or toxic gases are of prime importance in maintaining proper ventilation. In gassy mines, safeguards against gas ignitions depend largely on means for detecting, the presence of methane. Although the flame safety lamp is universally employed as a primary detector, it is not wholly suitable when accurate determinations are required. Much effort has been devoted to developing of improvements or attachments for lamps whereby more satisfactory determinations might be made without reference to personal ability in judging visual appearance of gas "caps." One notable achievement that resulted from this research was an attachment consisting of a coil of bimetal strip suspended in the upper part of the lamp. The lower end of the coil carries a pointer, the shadow of which moves over a scale as the bimetal coil winds and unwinds with changes in heat due to variations in the amount of gas entering the lamp. This device was developed in the Bureau's laboratories.

Considerable research has gone into the development of portable electric instruments of greater accuracy than the safety lamp for gas-detecting purposes. Research with electrical devices resulted in the development of several types of methane detectors, all of which are arranged for connection to the battery of miners' electric cap lamps as a source of current, as well as two devices having their own batteries for operation independently of cap lamps.3/ One of the latter gives a flashing signal with a lamp bulb when the methane content of the mine atmosphere reaches a predetermined value for which the instrument can be set, ranging from 0.25 to 3 percent methane. The remaining instruments are provided with scales calibrated to be read directly in percent methane. The Bureau of Mines has established schedules of fees, tests, and safety requirements to be met by safety lamps and gas detectors before they can be approved as permissible for use in gassy and dusty coal mines.

3/ Ilsley, L. C., and Hooker, A. B., Permissible Methane Detectors: Bureau of Mines Rept. of Investigations 3643, 1942, 10 pp.

Generated on 2024-09-19 22:17 GMT / https://hdl.handle.net/2027/osu.32435030643720
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from THE OHIO STATE UNIVERSITY

The complete analysis of mine atmospheres has been conducted mainly with apparatus of the gas-volumetric type such as the Orsat and Haldane. Modifications of such equipment have dealt principally with improvements in design to facilitate manipulation, development of interchangeable and unitized parts, provision of more effective gas-absorption vessels, adaptation of various methods of determining combustible gases, and securing greater precision.[4,5,6,7]

Methods and instruments for the specific detection and estimation of carbon monoxide have received particular attention because of the widespread occurrence and numerous sources of this gas. One early detector,[8] whose operation is based upon color production by reaction of carbon monoxide with a mixture of iodine pentoxide and fuming sulfuric acid, is insensitive to concentrations of carbon monoxide less than 0.1 percent, but it is capable of quickly indicating concentrations immediately hazardous to life. A later development, based upon the reaction of carbon monoxide with the hemoglobin of the blood,[9] is sensitive to 0.01 percent of carbon monoxide in air. During World War II a colorimetric indicator was developed that utilizes the reaction of carbon monoxide with compounds of palladium and molybdenum,[10] and which is sensitive to 0.001 percent carbon monoxide. Thus, continued research has produced a device whose sensitivity is a hundred times that of the initial development. A recently developed laboratory procedure, sensitive to 0.002 percent carbon monoxide, is applicable to the analysis of mine air samples of as little as 50 milliliters volume.[11] Portable indicators, actuated by

---

4/ Berger, L. B., and Schrenk, H. H., Bureau of Mines Haldane Gas Analysis Apparatus: Bureau of Mines Inf. Circ. 7017, 1938, 24 pp.

5/ Burrell, G. A., and Oberfell, G. G., The Use of Copper Oxide for Fractionation Combustion of Hydrogen and Carbon Monoxide: Ind. Eng. Chem., vol. 8, 1916, p. 228.

6/ Kobe, K. A., and Brookbank, E. B., Platinized Silica Gel as a Catalyst in Gas Analysis. II. Oxidation of the Methane Hydrocarbons: Ind. Eng. Chem., anal. ed., vol. 6, 1934, pp. 35-37.

7/ Berger, L. B., Determination of Carbon Monoxide by Absorption in the Haldane-Type Gas Analysis Apparatus: Bureau of Mines Rept. of Investigations 4187, 1947, 6 pp.

8/ Hoover, C. R., The Detection of Carbon Monoxide: Ind. Eng. Chem., vol. 13, 1921, pp. 770-772.

9/ Sayers, R. R., and Yant, W. P., The Pyrotannic Acid Method for the Quantitative Determination of Carbon Monoxide in Blood and in Air; Its Use in the Diagnosis and Investigation of Cases of Carbon Monoxide Poisoning: Bureau of Mines Tech. Paper 373, 1927, 18 pp.

10/ Shepherd, M., Rapid Determination of Small Amounts of Carbon Monoxide: Preliminary Report of the NBS Colorimetric Indicating Gel: Anal. Chem., vol. 19, 1947, pp. 77-81.

11/ Polis, B. D., Berger, L. B., and Schrenk, H. H., Colorimetric Determination of Low Concentrations of Carbon Monoxide by Use of a Palladium Chloride-Phosphomolybdic Acid-Acetone Reagent: Bureau of Mines Rept. of Investigations 3785, 1944, 13 pp.

Generated on 2024-09-19 22:14 GMT / https://hdl.handle.net/2027/osu.32435030643720
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from THE OHIO STATE UNIVERSITY

the heat of catalytic oxidation of carbon monoxide and capable of quantitative determination of low concentrations, are available.[12] Recording instruments,[13] based upon the same principle, are used to control ventilation in many vehicular tunnels.

Sensitive and accurate laboratory and field methods have been developed for the determination of hydrogen sulfide,[14] sulfur dioxide,[15] the toxic oxides of nitrogen,[16] and aldehydes.[17]

A recent interesting development in instrumentation is an oxygen indicator that is actuated by the paramagnetic properties of oxygen,[18] utilizing this effect to produce galvanometric indication of oxygen content.

The continued and increasing appreciation of the hazards to health caused by air-borne dusts, particularly siliceous dusts, has resulted in the development of numerous techniques for the evaluation of dusty atmospheres.

12/ Berger, L. B., and Schrenk, H. H., Methods for the Detection and Determination of Carbon Monoxide: Bureau of Mines Tech. Paper 582, 1938, 30 pp.

13/ Katz, S. H., Reynolds, D. A. Frevert, H. W., and Bloomfield, J. J., A Carbon Monoxide Recorder and Alarm: Bureau of Mines Tech. Paper 355, 1926, 34 pp.

14/ Littlefield, J. B., Yant, W. P., and Berger, L. B., A Detector for Quantitative Estimation of Low Concentrations of Hydrogen Sulfide: Bureau of Mines Rept. of Investigations 3276, 1935, 13 pp.

15/ Pearce, S. J., and Schrenk, H. H., Determination of Sulfur Dioxide in Air by Means of the Midget Impinger: Bureau of Mines Rept. of Investigations 4282, 1948, 6 pp.

16/ Beatty, R. L., Berger, L. B., and Schrenk, H. H., Determination of the Oxides of Nitrogen by the Phenoldisulfonic Acid Method: Bureau of Mines Rept. of Investigations 3687, 1943, 17 pp.

17/ Busch, H. W., and Berger, L. B., Sampling and Determination of Aldehydes in Diesel Engine Exhaust Gas and in Mine Air: Bureau of Mines Rept. of Investigations 4531, 1949, 9 pp.

18/ Pauling, L., Wood, R. E., and Sturdivant, J. H., An Instrument for Determining the Partial Pressure of Oxygen in a Gas: Jour. Am. Chem. Soc., vol. 68, 1946, pp. 795-798.

Generated on 2024-09-19 22:14 GMT / https://hdl.handle.net/2027/osu.32435030643720
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from THE OHIO STATE UNIVERSITY

The impinger method[19/20/] of sampling air-borne dust has received the most general application in the United States and is likely to continue as the more or less "standard" method for some time, as many studies of the physiological effects of inhalation of mineral dusts have been correlated with dust exposure as determined by the impinger method. Although this method is not effective in collecting ultra-fine particles, it does possess the advantage of producing a sample averaged or integrated over a time interval. The impinger as developed originally,[19/] required sampling at the rate of 1 cubic foot (28.3 liters) of air per minute, necessitating rather bulky apparatus and expenditure of considerable energy to sample at this rate. A later development, the midget impinger,[20/] samples at 0.1 cubic foot per minute, enabling collection of samples by a hand operated pump that requires only a small input of physical effort. Results obtained with the two types of impinger are comparable.

Devices such as the Owens jet dust counter[21/] and the thermal precipitator[22/] are used in the United States mainly for special purposes, as in the collection of samples for determination of particle-size distribution. The cascade impactor[23/] has received some application in situations requiring particle-size separation in sampling.

Electrostatic precipitation[24/] is employed to collect relatively large samples of dust that may be required for chemical or physical examination, or in instances where weight concentration of dust may be more significant than particle number concentration. Electrostatic precipitation is highly efficient but possesses the disadvantage that it may not be used with safety in situations where flammable gases may be encountered because of potential ignition hazard from the high-voltage energizing source.

As the hygienic significance of many mineral dusts centers upon the content of free silica, attention has been given to methods for quantitative determination of this component of dust samples.

19/ Greenburg, L., and Smith, G. W., A New Instrument for Sampling Aerial Dust: Bureau of Mines Rept. of Investigations 2392, 1922, 3 pp.

20/ Littlefield, J. B., Foicht, F. L., and Schrenk, H. H., Bureau of Mines Midget Impinger for Dust Sampling: Bureau of Mines Rept. of Investigations 3360, 1937, 4 pp.

21/ Owens, J. S., Suspended Impurities in Air: Proc. Roy. Soc. (London), vol. 101A, 1922, p. 18.

22/ Green, H. L., and Watson, H. H., Physical Methods for the Estimation of the Dust Hazard in Industry, with Special Reference to the Occupation of the Stonemason: Medical Council of the Privy Council, Special Reprint 199, H. M. Stationary Office, London, 1935.

23/ May, K. R., The Cascade Impactor: Jour. Sci. Inst. (British) vol. 22, 1945, pp. 187-195.

24/ Barnes, E. C., and Penney, G. W., An Electrostatic Dust-Weight Sampler: Jour. Ind. Hyg. and Toxicol., vol. 20, 1938, pp. 259-265.

Generated on 2024-09-19 22:17 GMT / https://hdl.handle.net/2027/osu.32435030643720
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from THE OHIO STATE UNIVERSITY

An X-ray diffraction technique has developed[25] that permits quantitative determination of quartz in concentrations as low as 1 percent in samples of 3 to 5 milligrams. Smaller quantities may be examined but the difficulties of preparation and manipulation of the sample are increased.

Petrographic techniques[26] are employed to establish the identity of mineral materials in quantities of dust too small to be examined by other methods. Free silica may be determined on a semi-quantitative basis in samples of air-borne dust collected by the impinger method when the total quantity of dust collected is not sufficient to permit analysis by chemical methods or by X-ray diffraction.

Oxygen Breathing Apparatus, Respirators and Gas Masks

The status of respiratory protection in the United States in 1910 was far different from that in 1950. At that time there were no gas masks, dust respirators were flimsy and inefficient, hose masks were rudimentary, and loose fitting smoke helmets and imported oxygen breathing apparatus were the only respiratory protection available for mine rescue and recovery operations.

Self-contained oxygen breathing apparatus were introduced in the United States in the summer of 1907. The first of these were imported from Europe. There were three types, - Draeger, Westfalia, and Fleuss or Proto. The operating principle was generally the same for these apparatus. Compressed oxygen from cylinders in combination with oxygen from regenerators was stored in breathing bags. All had a constant flow of oxygen.

Experience in mines with these early types of apparatus revealed many shortcomings, and the Bureau of Mines undertook active experiments to improve them. As a result, standards were set up for permissible self-contained mine rescue breathing apparatus.

The Gibbs 2-hour apparatus, developed from the experimental and research data obtained by the Bureau of Mines was designed in about 1917 and was approved by the Bureau of Mines as permissible in 1920. Subsequently the Paul, the McCaa, the Fleuss-Davis Proto, and the Draeger were approved by the Bureau of Mines; still later the improved McCaa, redesigned and renamed the Mine Safety Appliances Co. apparatus, was approved.

Changes in approval requirements by the Bureau of Mines and the need for improvements brought out by the use of the oxygen breathing

---

25/ Ballard, J. W., Oshry, H. I., and Schrenk, H. H., Quantitative Analysis by X-ray Diffraction. I. Determination of Quartz: Bureau of Mines Rept. of Investigations 3520, 1940, 10 pp.

26/ Foster, W. D., and Schrenk, H. H., Petrographic Identification of Atmospheric Dust Particles: Bureau of Mines Rept. of Investigations 3368, 1938, 10 pp.

Generated on 2024-09-19 22:16 GMT / https://hdl.handle.net/2027/osu.32435030643720
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from THE OHIO STATE UNIVERSITY

apparatus caused many modifications to be made. Refillable regenerators were approved, and the metal was changed from steel to copper for longer life. Cardoxide composed of hydrated lime, sodium hydroxide, and water was used as an absorbing agent because of its nonagglomerating and superior carbon-dioxide absorbing properties. Other mechanical improvements and substitutions of aluminum for steel made a better-functioning and lighter apparatus.

The Chemox self-generating oxygen breathing apparatus was approved by the Bureau of Mines on October 3, 1946, for a three-quarter hour wearing period. This apparatus develops its own oxygen and removes carbon dioxide from the exhaled breath. The primary parts are a Chemox canister, breathing bag, and full face piece with valves to control the direction of flow. Moisture in the breath liberates oxygen from the potassium tetroxide in the canister for the oxygen supply.

Two one-half-hour demand types of self-contained breathing apparatus were approved by the Bureau of Mines on October 3, 1946. The primary parts are a cylinder for compressed air, or oxygen, demand-type reducing or regulating valve, and a gas mask face piece. Oxygen, or air, is supplied to the wearer on inhalation, and the exhaled air is passed to the outside atmosphere.

In 1917, the Bureau of Mines was assigned the task of developing gas masks suitable for protecting Army personnel against war gases and smokes. This work, merged with the Chemical Warfare Service in 1918, resulted in the development of an efficient gas mask facepiece, a catalyst for the oxidation of carbon monoxide, granular absorbents for acid gases, organic vapors, and ammonia, and very efficient aerosol filters. Much fundamental work was done on the efficient use of these materials, and suitable methods were developed for testing their efficiency. This war work by the Bureau of Mines was the groundwork upon which was based the development of respiratory protective devices in the United States.

Immediately after World War I many serious accidents were caused by attempts to use the Army service mask for protection against carbon monoxide, ammonia, and atmospheres deficient in oxygen. It became evident that there was real need for an educational campaign on the use and limitations of Army gas masks and development of a standard of performance for gas masks that were to be sold in the United States. Accordingly, in 1919 the Bureau of Mines prepared Schedule 14, which set forth the minimum performance requirements that gas masks should meet to be approved for safe use in mines and industries.

To assist industry in adapting the Army gas mask to industrial uses the Bureau of Mines developed a universal and a fireman's gas mask, a pocket respirator for use by trainmen in railroad tunnels, an activated absorbent carbon from coal, and a variety of other substances. Protection against carbon monoxide was provided by the action of the "Hopcalite" catalyst in the canister, which oxidized carbon monoxide to carbon dioxide. The Bureau's schedule for permissible gas masks

Generated on 2024-09-19 22:17 GMT / https://hdl.handle.net/2027/osu.32435030643720
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from THE OHIO STATE UNIVERSITY

has been revised five times, and each time the requirements have been made more severe.

Although supplied-air respirators such as smoke helmets, sand-blast helmets, and hose masks were used quite widely, there were no performance standards governing them prior to 1927, when the Bureau of Mines prepared Schedule 19, which set forth the minimum performance requirements for hose masks.

In 1928 the Bureau carried out a series of tests on the filtering efficiency of dust respirators[27] and developed a dust respirator in the form of a hat with a large filtering area. In answer to widespread demand, the Bureau prepared Schedule 21[28] in 1934, which set forth the minimum performance requirements for dust, fume, and mist respirators.

Preparation of these Schedules required much research and test work in order that the Schedules would perform their intended function. At the time these Schedules were issued, no respirators that would meet their requirements were being produced commercially in the United States. However, the demand for approved respirators of all types caused the manufacturers to develop respirators that would meet, and in many instances greatly exceed, the Schedule requirements. Thus, the Bureau's Schedules have been instrumental in the development of better respirators in the United States. Each time a Schedule has been revised, the performance requirements have been made more severe; and each time the manufacturers have been able to develop respirators that would meet these requirements. In the course of its testing work, the Bureau of Mines has aided considerably in the development of all types of respiratory devices by suggestions made to the manufacturers prior to formal submission of the devices to the Bureau for approval, by determining the cause of failure of respirators which do not meet the Schedule requirements, and by making suggestions for correction of the faults.

At present, approved models of virtually all needed types of respiratory protective devices are commercially available. The list of respiratory protective devices approved by the Bureau of Mines contains 11 styles of self-contained breathing apparatus, 45 gas masks, 24 supplied-air respirators of various types, 59 dispersoid respirators, and 5 chemical cartridge respirators.

Electrical and Mechanical Equipment

When the Bureau of Mines was established in 1910, it was already recognized that electrical equipment and circuits in coal mines were hazardous under certain conditions, and, accordingly, one of the

---

27/ Katz, S. H., Smith, G. W., and Meiter, E. G., Dust Respirators, Their Construction and Filtering Efficiency: Bureau of Mines Technical Paper 394, 1926, 52 pp.

28/ Bureau of Mines, Procedure for Testing Filter-Type Dust, Fume, and Mist Respirators for Permissibility: Bureau of Mines Schedule 21, 1934, 14 pp.

Generated on 2024-09-19 22:16 GMT / https://hdl.handle.net/2027/osu.32435030643720
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from THE OHIO STATE UNIVERSITY

duties of the Bureau from the outset was to determine the causes of and means for preventing accidents having electrical origin.

The investigations of hazards not associated with specific devices or equipment include the following:

1. Action of acid mine water on insulation of electric conductors.

2. Ignition of natural gas-air mixtures by heated surfaces.

3. Ignition of coal by electric circuits in coal mines.

4. Ignition of coal dust by electric arcs.

5. Ability of fuses to prevent gas ignition when fuse-protected cables are damaged.

6. Dry cells and their application to mining.

7. Ground resistance measurements of electrical equipment in and about coal mines.

8. Static electricity in nature and industry.

9. Safe current-carrying capacities for bare copper conductors in contact with wood and other combustible materials.

Electric Lamps. It was realized that open flames of carbide and oil lamps not only provided inadequate illumination, and thus contributed to accidents but also that these flames were ever-present fire- and gas-ignition hazards. Early studies of miniature incandescent electric bulbs then becoming available showed that their filaments when exposed were capable of igniting methane-air mixtures. Crude attempts at devising miners' portable lamps with these miniature bulbs were seen to need guidance and encouragement if safe lamps were to be produced for general use in gassy mines. Thus, it was that the Bureau of Mines prepared a set of standards or minimum requirements to be met in producing safe lamps. Since 1914, when the first approval was granted, great strides have been made in improving the amount of light, durability, efficiency, and other important features of portable lamps. Today, many hundred of thousands of permissible electric cap lamps are used in gassy as well as nongassy mines, both in the United States and abroad.

Telephones and Signaling Devices. - Examination of existing mine telephones proved them capable of igniting gas by sparks produced when the current from the magneto ringer was interrupted. Based on this and other studies, a schedule of fees, tests, and safety requirements was established. Under this schedule, one magneto-type and four sound-powered telephones have been approved by the Bureau. The latter type may be classed as intrinsically safe, no batteries being required in their operation. Moreover, two of these telephones employed mechanical

Generated on 2024-09-19 22:16 GMT / https://hdl.handle.net/2027/osu.32435030643720
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from THE OHIO STATE UNIVERSITY

rather than electrical means of producing audible signals. The remaining two telephones were equipped with magneto ringers so "protected" that igniting currents were not transmitted over the telephone circuit.

In an adaptation of the sound-powered telephone to mine rescue and recovery work, the life line consists of a cable for the telephone circuit. This adaptation permits the advance crew, while wearing respiratory protective equipment, to maintain contact with men at the fresh-air base without danger of igniting gas that may be present.

The development of portable equipment to provide a means whereby trapped miners might communicate with rescue workers, has been given careful study by the Bureau of Mines. Although the results have been encouraging, the hoped-for solution has not been fully achieved. However, an achievement incidental to this research has been the commercial development of "trolleyphones", which permit mine locomotive operators to keep in constant communication with each other and with dispatchers and thus promote safe and efficient operation of trolley haulage systems.

Blasting Devices. - Misfires and premature ignition of explosives in coal mines have been the subject of intensive investigation. Laboratory and underground studies have shown that leakage of current from the blasting circuit, insufficient capacity of blasting generator, and high resistance are among the factors responsible for misfires. The studies also have shown that differences of potential between various metal objects, such as pipes and rails, arise from grounded trolley and other electric power circuits have been the frequent cause of accidental firing of blasting caps, the leg wires of which came in contact with conductive objects and materials not a part of the blasting circuit. Schedules covering fees, tests, constructional requirements as to capacity, etc., have been published to promote the development of more satisfactory single-shot and multiple-shot blasting units that will aid in reducing hazards of misfires and accidental firing. Under these schedules, 30 single-shot and 7 multiple-shot blasting units have been approved by the Bureau of Mines.

Diesel Locomotive and Diesel-Powered Mobile Equipment. - Direct-current trolley locomotive haulage systems have been responsible for fatalities through contact with the trolley wire, through fires started by arcs from fallen wires, through gas ignitions by sparks at the current collectors, and through premature explosions by current straying from the grounded rail return circuit. These accidents have led to the proposal that trolley locomotives be replaced by Diesel locomotives. A number of engines were procured and studies were made to determine (1) the toxicity of the exhaust gases under various conditions of operation; (2) effectiveness of flame arresters at elevated temperatures as compared to room temperatures, and (3) improvement of water-scrubber efficiency by addition of chemicals.

Two schedules giving the conditions under which approvals of Diesel-driven equipment would be granted were published. One of

Generated on 2024-09-19 22:14 GMT / https://hdl.handle.net/2027/osu.32435030643720
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from THE OHIO STATE UNIVERSITY

these covers conditions applying to Diesel locomotives for gassy mines, and the other covers conditions applying to mobile Diesel-powered equipment for noncoal mines. Although two formal applications are on file, no approvals of locomotives or other Diesel-powered equipment have been granted.

Equipment for Mechanized Mining. Electric motor-driven equipment has been highly developed and widely applied in the mechanization of coal mines. To investigate means of reducing gas ignition hazards, five motors designed to be explosion-proof were tested in explosive methane-air mixtures. This investigation led to the establishment of requirements for motors, starters and other electric components of machines for cutting, drilling, loading, transporting, and other mechanical operations in mines. Under these requirements now published as schedules, more than 600 approvals have been granted. Today, permissible (approved) equipment is available for virtually any necessary operation in face areas of gassy coal mines. The Federal Mine Safety Code for Bituminous-Coal and Lignite Mines of the United States requires that "all new electric face equipment and replacements of equipment purchased for mines where nonpermissible equipment is now being used shall be of a permissible type approved by the United States Bureau of Mines." This requirement is intended to aid in the reduction of fires and explosions of electrical origin.

Various problems involving safety in the design, operation, and use of permissible machines that have been given careful study include the following:

1. Flammable gases produced by thermal decomposition of plastic insulators in an electric arc as a possible explanation of bursting of explosion-proof enclosures.

2. Flame-arresting limitations of flat joints and plain bearings in explosion-proof equipment.

3. Abnormal pressures in explosion-proof enclosures of mining equipment.

4. The explosibility of methane-air and gasoline-air mixtures as related to the design of explosion-proof electric motors.

5. Ignition hazards from brake shoe sparks, electric current leakage over battery cell tops and from failure to ventilate battery boxes of storage-battery locomotives.

6. Overheating, splicing, durability, and flame-resistance of trailing cables used with mobile and portable mining equipment.

7. Toxic gases produced by trailing cables when overheated or burned.

8. Standardization of dimensions for cables of circular and oval section.

Generated on 2024-09-19 22:20 GMT / https://hdl.handle.net/2027/osu.32435030643720
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from THE OHIO STATE UNIVERSITY

Prevention of Roof Falls

Roof falls have caused more serious injuries and fatalities in American coal mines than any other single hazard. Throughout the years the Bureau has collected data on the nature of roof falls in different rock formation and under various conditions of mining. Recommendations have been made on the basis of such studies on appropriate methods of roof support, and much time has been given to educating the miners to exercise greater care in working on the safe side in supporting roof in working places. Much research has been conducted by both the Bureau of Mines and the coal-mining industry in trying to develop loose roof detectors of various kinds, but with little success in finding a simple practical instrument. Although some progress has been made in developing safer roof-control operations over the years, it was not until a few years ago that a technique of roof bolting which had previously been developed in metal-mines, showed promise for better roof support in coal mines.

Holes are drilled into the roof either vertically or at an angle with the bedding planes, and mild steel rods 1 inch (2.54 cm.) in diameter are inserted in the holes. The rods are threaded at one end and are slit at the other. They are anchored at the back end of the hole by driving the slit end of the rod over a steel wedge which expands the end of the rod. The rods are then placed under tension by tightening the nuts on the threaded end on a bearing plate at the collar of the hole, with a power wrench.

The effect of roof bolting is to consolidate several thin strata to form a thicker and more competent beam across a mine opening than the thin individual strata.

A trial of this method of roof support in several coal mines showed that it becomes totally effective almost immediately after the coal has been extracted, and that it provides extra working space by eliminating conventional timber and thus promotes efficient operation of mechanical face equipment. Operation of this roof-bolting method has spread to many mines in the last 2 years. It is significant that many coal deposits heretofore considered unminable because of an extremely bad roof are now being mined safely and economically with the use of roof bolts.

At the end of 1949 approximately 200 coal-mining companies were utilizing the method to support approximately 14 million square feet (1.3 million square meters) of roof surface. About 75 percent of these projects were initiated after April 1, 1949 when virtually all of the mechanized mines in the United States were either planning experimental installations or were preparing "to jump head first" into roof bolting. Moreover, many metal mines became interested in roof bolting as a result of this activity. Ninety percent of the production of one group of mines in Alabama producing 5.5 million

Generated on 2024-09-19 22:17 GMT / https://hdl.handle.net/2027/osu.32435030643720
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from THE OHIO STATE UNIVERSITY

tons of iron a year is now mined under bolted roof. This change over was made since the summer of 1948.

Roof bolting promises to be one of the most important contributions to the control of roof in coal mines in modern times, not only to reduce the number of accidents and injuries from falls of roof but also to improve operating efficiency at the working faces. Obviously, this method of roof support is not applicable to any and all mining conditions; however, after experimental installations have proved the practicability of roof bolting, specific equipment is necessary to exploit the possibilities of the method to the fullest extent.

PROBLEMS YET TO BE SOLVED IN MINE SAFETY RESEARCH

Gratifying as the collective achievements of our mine safety research stations may have been over the past 40 years, we realize that too many knotty problems have been only partly solved and that new mechanical developments in mining present new hazards to health and safety. The old refractory problems and the unsolved new ones present a real challenge for continued effort towards the ultimate in mine safety. It is the main purpose of these international conferences to aid each other in planning the most effective programs for improvement in mine safety and for that purpose we need to know the unsolved or only partly solved problems that are awaiting a final or more complete solution. As in my review of achievements in mine safety research, I will discuss the unsolved problems under the headings of (1) explosives, (2) dust explosions, (3) gas explosions, (4) ventilation, mine air, and air-borne dust, (5) oxygen breathing apparatus, respirators, and gas masks, (6) electrical and mechanical equipment, and (7) prevention of roof falls.

Explosives and Their Use

High on our priority list is the problem of the mechanism of the ignition of fire damp. Although it has been shown that very material progress has been made in this subject, effort should be renewed to establish a true mechanism of this reaction and apply it to the eventual solution of preventing mine explosions due to the presence of this gas. It is believed that the rapid development in the field of high-speed photography will greatly accelerate the work on this fundamental problem.

The continual desire of industry to increase output without increasing actual labor demands the use of the maximum charge limit of explosives consistent with safe practice. Already there have been suggestions of the possibility of increasing the 3-pound (1,361 gram) limit now in effect. However, no such change could be considered without further exhaustive study of the ignition hazard associated with an increase in the weight of charge. Multiple blasting by use of millisecond delays has been advanced as another method of increasing

Generated on 2024-09-19 22:16 GMT / https://hdl.handle.net/2027/osu.32435030643720
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from THE OHIO STATE UNIVERSITY

production. Although it is possible that such a method may not materially increase the explosion hazard, the problem is really rather complex from the standpoint of safety. Investigation of the ignition hazard would only partly solve the problem of safety, as the possibility of undetected misfires represents a problem of importance second only to that of ignition. A method is needed, in multiple-shot blasting, to indicate the charges that fail to detonate.

The problem of stemming shot holes deserves a great deal more study in the future. Present methods of stemming are relatively time-consuming and expensive, but faster substitute methods have not been investigated sufficiently to warrant relaxation in the general standards.

A complete reappraisal of the test methods used in determining permissibility is contemplated for the forseeable future. Although older methods have proved satisfactory, as shown by the safety records, it is believed that application of the newer test equipment developed in other industries should be applicable to even routine testing of explosives.

Increasing use of blasting devices such as Cardox, Airdox, etc., indicates the desirability of new investigations to determine their general relationship to problems of mine safety. These investigations should include not only investigation of ignition hazards associated with fire damp and coal dust, but also the effect of the devices on roof structures and supports.

Consumption of liquid-oxygen explosives in open cut mining the United States has reached a point where it must be considered a factor in the explosives field, but the future development of this industry will depend largely on the promotion of greater safety in its utilization. The Bureau of Mines is currently engaged in an investigation to develop safer liquid oxygen absorbents and to further study its burning behavior characteristics. Other projected developments that would contribute substantially to greater safety are (1) development of an acceptable fireproof wrapper and (2) development of a practical method of mixing the explosive in the borehole in order to minimize the exposure of personnel to the dangers associated with the finished explosive.

Dust Explosions

More fundamental investigations are needed to broaden our knowledge of the mechanism of the ignition of flammable dust particles and the propagation of flame through dust clouds. This would be of great value in formulating research aimed at inhibiting the ignition of dust or arresting the combustion during its initial stages.

Generated on 2024-09-19 22:21 GMT / https://hdl.handle.net/2027/osu.32435030643720
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from THE OHIO STATE UNIVERSITY

The most practical current measure for preventing explosion propagation in mines is the rock dusting of mine workings. As now practiced this method is not ideal. The quantity of rock dust required in proportion to the coal dust is great; its effectiveness is reduced by fresh deposits of coal dust, which is being produced constantly; frequent redusting is needed; and difficulties are experienced occasionally as a result of caking and loss in dispersibility. Furthermore, it is often difficult, if not impossible, to apply rock dust in the important areas close to rapidly advancing faces, and many mines cannot afford to purchase rock-dusting machines and must resort to less efficient hand distribution. To overcome these and other problems, research is needed (1) to determine the most effective proportions of rock dust on the floor, ribs, and roof of mine entries, respectively; (2) to develop more efficient methods for distributing rock dust in rooms than by hand spreading; (3) to study the value of inert dusts other than limestone and shale, which are now in most common use; (4) to evaluate the possibilities of complementing generalized rock dusting by dispersing rock dust into the path of the explosion flame directly from devices that are free from the defects of the conventional rock dust barriers; and (5) to investigate different measures for arresting the flames, as by use of water sprays, water barriers, chemical inhibitors, and other agents.

More effective means of allaying the air-borne dust made by continuous mining machines should be developed. Although water sprays are used on these machines, a more positive dust control is desirable.

A means should be developed to permit the application of rock dust during the working shift as the face advances. Face rock dusting would materially reduce the possibilities of the propagation of an explosion.

Gas Explosions

Many problems dealing with gas-explosion hazards are still unsolved and new problems develop with the advancement of new technologic processes. To satisfy needs in connection with safety in mining and new industrial developments, facilities for determining explosion hazards must be adapted continually to the new conditions; as examples, one may cite (1) the explosibility of gaseous combustible mixtures at greatly reduced pressures, simulating combustion processes at high altitudes, and (2) explosibility at high pressures, simulating conditions now used in the secondary oil recovery processes, whereby natural gas-air mixtures are forced through partly depleted oil sands to increase the recovery of oil.

Extended research is required to determine the explosion hazards of combustible gases and vapors at high pressures to keep pace with the many new industrial processes now employing high pressures to carry out reactions in the presence of combustible materials. It is known that the explosive limits of methane and natural gas in air are widened markedly as the pressure is increased, and processes that are

Generated on 2024-09-19 22:14 GMT / https://hdl.handle.net/2027/osu.32435030643720
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from THE OHIO STATE UNIVERSITY

normally safe at atmospheric pressure may become exceedingly hazardous at elevated pressures.

Information is needed relative to the explosion hazards of the many high-boiling hydrocarbons now used extensively in industry. For example, hydraulic fluids now used in the operation of certain mining equipment have caused fires in mines. The explosion hazards of using such fluids should be determined, and efforts should be made to find either substitute fluids having nonflammable properties or materials that may be added to now used hydraulic fluids to render them nonflammable.

The prevention of explosions by the addition of the usual inert gases such as nitrogen, carbon dioxide, helium, and exhaust or flue gases is now rather complete for atmospheric pressure conditions, but little is known about the quantities required to prevent explosions at elevated pressures and temperatures.

Numerous flame-quenching materials comprising chlorinated and fluorinated hydrocarbons are now coming on the market, some of which may be of marked value in the prevention of fires and explosions in enclosed spaces. These should be investigated to determine their merits.

Flame propagation studies dealing with the physics and chemistry of flames in quiescent and flowing mixtures, including turbulent streams and studies of simultaneous mixing and burning processes should be carried out. The stabilization of flames, flame structure, and flame extinction are part of the program.

The great number of mine fires that occur in spite of the information now available requires increased activity and research to improve present methods of fighting mine fires. Efforts should be made to find and extinguish fires at the start, thus eliminating the eventual requirement of sealing the area, with resulting loss of coal production and additional expense in putting the sealed area back into workable condition. The use of suitable detecting and recording equipment installed at strategic locations in mines, which will indicate at all times the amount of combustible gas present, and other equipment to record the presence of heat and smoke is desirable. Such information would enable the management to locate the trouble area quickly and to take prompt action to eliminate a potential explosion hazard or put out a fire before it could become dangerous.

There is need for research to develop means of localizing explosions through the use of flame arresters, release diaphragms, rupture disks, or combinations of these, in closed spaces or conduits where flammable gases or dusts may be present. Flame arresters and rupture disks have been in use for the protection of tanks and similar equipment containing combustible mixtures. However, localizing explosions in long pipe lines and other extended systems becomes increasingly difficult owing to pressure "piling" of the explosion and movement of the gases through the pipes as the flame progresses.

Generated on 2024-09-19 22:16 GMT / https://hdl.handle.net/2027/osu.32435030643720
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from THE OHIO STATE UNIVERSITY

Flame arresters are of questionable value in these instances unless diaphragm releases are installed in conjunction with them. The spacing and number of release diaphragms and flame arresters in a given system to localize explosions cannot be predicted at present owing to lack of information on the subject.

Ventilation, Mine Air, and Air-borne Dust

The scientific and engineering advances in the fundamentals of air movement in general have been very great in the past 20 years. However, much of this recent knowledge has not been applied as far as it could have been in the ventilation of coal and metal mines. There still remains a good deal of empiricism on the part of mining engineers. An important problem of the near future is to simplify and make more available known engineering and scientific data for designing and operating better systems of ventilation. This need is especially great in connection with the introduction of the newly developed continuous mining machines in America which advance the working face so rapidly that very large volumes of methane may be released, requiring special auxiliary ventilation in the working places to prevent the occurrence of flammable concentrations of methane in the mine air.

A desirable development would be the equipment of these mining machines with a dependable automatic instrument for detection and warning of the presence of methane in concentrations approaching the lower explosive limit.

Another great safety measure would be the degasification of the coal bed in advance of the working face, either by drilling holes from the face or from the surface to the coal bed. Practical trials thus far made have not met with much success, but further studies in various types of coal beds and associated roof and floor strata should be made.

From the economic and also the safety points of view more durable and less combustible materials are desired to replace ordinary canvas or jute brattices and ventilation tubes or conduits. These may be destroyed by fire, fungus rot or acid mine water. Consideration should be given to plastics, fiber glass, and other ceramic materials.

Excellent analytical methods are in use for the laboratory examination and analysis of samples of mine air, road and rib dusts, and air-borne dust occurring in mines and mineral industry plants. However, there is great need for instruments and methods for making on-the-spot tests for determining the percentage of rock dust in the road and rib dusts of coal mines. Although the flame safety lamp and several types of electrical methane indicators are available, there is room for a more positive gas-indicating type of safety lamp and the accuracy and durability of the electrical types of indicators could be improved.

Generated on 2024-09-19 22:17 GMT / https://hdl.handle.net/2027/osu.32435030643720
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from THE OHIO STATE UNIVERSITY

Future efforts toward development of techniques for the collection and examination of air-borne dusts might include:

1. A method for collecting enough dust samples in coal mines to determine free silica by X-ray diffraction. Such dust-collecting system would require an actuating source permissible for use in situations where flammable atmospheres might exist.

2. Improvement of chemical or physical methods for the determination of free silica in small samples of air-borne dust.

3. Determination of the effect of air velocities, of the magnitude encountered in mines, on the results of air-borne dust-sampling by existing techniques.

4. Further studies of charges upon particles and the effects of surface-active agents as related to the collection of dust from air.

5. As some investigators are attaching increasing significance to the physiological action of the finer particles, the electron microscope and electron diffraction might offer possibilities for extending the study of air-borne dusts into the range of particles not distinguishable by ordinary microscopic methods.

Oxygen Breathing Apparatus, Respirators, and Gas Masks

Remarkable progress has been made in all countries in the last 20 years in the development of improved oxygen breathing apparatus, respirators and gas masks. The crude equipment for respiratory protection available in 1920 has been replaced by dependable equipment, and in the United States this can be had as permissible according to tests by the Bureau of Mines.

One of the chief problems confronting those engaged in respiratory work is the education of the worker to wear the proper type of respiratory protective device when exposed to harmful atmospheres. The main objection to present respirators is that they are uncomfortable to wear for extended periods for one or more of the following reasons: They are too bulky, too heavy, too flimsy, too complicated; their service time is too short; they do not fit the wearer's face comfortably; and the full facepieces cannot be worn with prescription glasses.

Future research should be devoted to developing devices in which these objections are overcome. There is need of further research on mechanical filters for the removal of dispersoids, on absorbents and catalysts for the removal or conversion of toxic gases, and on facepieces of all types to provide more comfortable fit on a greater variety of facial shapes and sizes and to permit for the use of prescription glasses with full facepieces. The ultimate in respiratory protection has not yet been achieved.

Generated on 2024-09-19 22:16 GMT / https://hdl.handle.net/2027/osu.32435030643720
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from THE OHIO STATE UNIVERSITY

Electrical and Mechanical Equipment

The use of electricity for haulage, operation of mechanical equipment, and lighting has progressed tremendously in American mines. It has introduced many new safety hazards, but, on the whole, the new problems have been solved as they developed. However, we still need better solutions to some of our safety problems related to the use of electricity.

1. The growth of mechanized mining and loading demands flood lighting of the entire working places. Good illumination makes possible greater productivity per man and fewer accidents.

2. A fire-resistant insulating substance that will not liberate irritating fumes and gases when subjected to overheating is needed for trailing cables.

3. There is need for improving reeling and unreeling devices on mobile equipment. Present devices do not prevent conductors in the cable from being broken, run over, or pulled apart.

4. Improved methods for grounding the frames of electric equipment should be developed not only because the frames may become charged and present a shock hazard, but because under certain conditions, when grounding is inadequate, arcs and sparks may occur where the frame of one piece of mobile equipment contacts another.

5. There is a great need for more positive protection of electrical equipment and circuits against overload and short circuit. Many fires have been attributed to the lack of adequate protective devices.

6. A fire-resistant substance should be developed for use in the construction of conveyor belts. Many serious fires have occurred in connection with belt conveyors, but fortunately none to date has resulted in loss of life.

7. Improved means of communication between each working section underground and the surface should be developed. This system should not be dependent on either trolley, rail, or feeder wire for its source of power. Many lives have been lost in recent years because of the lack of a means of communication between entombed men and the surface. Intrinsically safe circuits for signal bells and remote-control systems should be developed to reduce ignition hazards associated with present systems.

8. A method of detecting defective or faulty trolley hanger insulators without disconnecting the trolley wire should be developed to aid in preventing mine fires caused by leakage of current.

Generated on 2024-09-19 22:17 GMT / https://hdl.handle.net/2027/osu.32435030643720
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from THE OHIO STATE UNIVERSITY

Prevention of Roof Falls

The recent development of roof bolting to prevent falls in the coal mines of the United States is the most promising solution that has yet been tried, for it offers a needed method to gain and maintain control of the roof close to the face as the face advances, especially where a continuous mining machine is used. Control of the roof to the face is difficult in a continuous operation, because the size of the machine and rate of advancement are such that large roof areas are exposed rapidly and the machine hampers the work of installing roof supports between the back end of the machine and the face. A device to indicate the roof conditions is highly desirable. Mechanical equipment now in use makes so much noise that workers often fail to hear the sounds given off by a falling roof, and a device should be developed to allay or collect the dust formed by drilling dry roof holes. A high percentage of dust from roof drilling becomes air borne and this dust may be hazardous to the health of workmen.

Roof control in general and roof bolting in particular would be greatly benefited, both as to safety and economy, if more engineering knowledge were available regarding the behavior of mine roof, particularly the distribution of stresses about mine operations in stratified rock. The Bureau of Mines is equipping a roof-control laboratory, and a crew is at work in the field with a newly developed "stratascope" gathering basic data. Preliminary experiments show considerable promise, but it will probably be some time before information can be obtained to justify definite conclusions for the industry.

Meanwhile, for the sake of safety, the roof-bolting problem must be worked out the "hard way" at each mine — namely, experimental roof-bolt installations must be made in the proper underground locations, using conventional timbering and conventional methods of mining and then removing the timbers. The duration of an experimental period should be governed by previous experience in the particular coal bed and field; the regularity of bedding, such as freedom from unpredictable slips, faults, horsebacks, etc., and by the ease by which the roof bolting can be fitted into the normal mining cycle without gaps in the continuity of bolting. Neither rooms nor entries should be driven wider than is done with the conventional timbering system until it is proved beyond doubt that the roof of the opening of conventional width can be supported safely with roof bolts; and then, if wider openings are contemplated, a new experimental installation should be undertaken. Moreover, if any significant changes occur in the characteristics of the roof, a new experimental period with conventional timbering should be undertaken.

Generated on 2024-09-19 22:15 GMT / https://hdl.handle.net/2027/osu.32435030643720
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from THE OHIO STATE UNIVERSITY

SUMMARY

In concluding this review of the achievements in mine-safety research and the problems yet to be solved, it is apparent that much has been accomplished in the past 40 years. However, it is also evident that more remains to be done before we have any right to feel that health and safety conditions in the mining industry are as satisfactory as they can be made.

In the United States the average number of lives lost annually per 100,000 men employed in coal mining has been reduced from 394 to 203 in this period, which is 48 percent. Gas or dust explosions, the spectacular causes of deaths in large groups, caused 71 deaths annually per 100,000 men employed in the 5 years ended in 1910 and 15 deaths annually in the 5 years ended in 1949. This is a reduction of 79 percent. Research at our various mining experiment stations may take a great deal of credit for this great reduction in fatalities.

Research has put up two effective lines of defense against such explosions. The first line was to prevent ignition, and the second was to stop propagation. Ignition has been prevented by the proper use of permissible explosives, electric lamps, and permissible electrical equipment. Propagation has been stopped by adequate ventilation to remove methane and by generalized rock-dusting to render coal dust nonflammable.

Such explosions as have occurred in recent years usually could be traced to the violation of some of the known rules of safe practice, such as smoking, opening flame safety lamps, use of nonpermissible explosives, or failure to maintain adequate rock dusting throughout the mine at all times.

The electric cap lamp in American mines has not only eliminated a great ignition hazard, but also has greatly improved the efficiency of coal production by providing much better illumination, and has decreased materially the accidents that are caused by poor lighting.

The widespread introduction of rock dusting of American coal mines was made possible by the development of rock dust-spreading machines, which can spread up to 300 pounds (136 kg.) of rock dust per minute. There is a further need for the development of mechanical means of rock-dusting working places up to within 40 feet (12 meters) of the face.

Maintenance of electrical equipment underground in safe permissible condition requires constant supervision; otherwise insulation may become worn and cause sparks or arcs, or protective enclosures may be loosened and permit explosive mixtures of dust or gas to gain entry to sources of ignition. The continual growth of mechanized mining in the United States imposes a succession

Generated on 2024-09-19 22:15 GMT / https://hdl.handle.net/2027/osu.32435030643720
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from THE OHIO STATE UNIVERSITY

of new problems in approval of permissible equipment. We sometimes think that we are fortunate in keeping pace with the safety requirements of these new developments.

The decrease in fatalities from gas and dust explosions and also from handling explosives in the last 40 years has been about 80 percent. The decrease from other causes have been electrical contacts, 56 percent; falls of roof and coal, 39 percent; and haulage, 24 percent.

TABLE 1. - Percentage distribution of fatalities from different causes in coal mines of the United States in the 5-year periods ended in 1910 and 1949

Cause	1906-10, inclusive, percent	1945-49, inclusive, percent
Roof and coal falls.....	44	52
Gas and dust explosions.....	18	7
Haulage.....	12	18
Handling explosives.....	8	3
Electrical contacts.....	2	2
Other causes underground including shaft and slope.....	9	7
On surface and in strip mining.....	7	11

Table 1 shows a comparison of the percentage distribution of fatalities from different causes in mines of the United States in the 5-year periods ended in 1910 and 1949. Throughout the 40 years that it covers, roof and coal falls were responsible for about half of all fatalities. Gas and dust explosions occupied second place, with 18 percent, in the 1906 to 1910 period, and third place, with 7 percent, in 1945 to 1949. Haulage fatalities shifted from third place, with 12 percent, in the first period, to second place in the last period, with 18 percent of the total fatalities. Falls, explosions, and haulage caused 74 percent of the fatalities in 1906-1910 and 77 percent in 1945-49.

These three classes of hazards contain most of the problems yet to be solved in our safety research. Some of the problems are scientific and technologic, but many of them are problems dealing with human nature and mine management.

Generated on 2024-09-19 22:15 GMT / https://hdl.handle.net/2027/osu.32435030643720
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from THE OHIO STATE UNIVERSITY

Roof falls deserve the most serious attention from both the research and the operating points of view. Geophysical studies on the strength of roof materials and the possibility of improvement by roof bolting or other methods give promise of fundamental information that may be utilized in practical underground experimentation.

Next in importance to roof-fall prevention is a reduction in haulage accidents. More thought should be given to the analysis of these accidents with a view to safer designs of haulage lay-outs and safer operating schedules of haulage equipment. Both management and miners should be made aware of the necessity of more effective safety training in this respect.

For further reduction of fatalities from gas and dust explosions we need a more general application in mining practice of knowledge gained from research. Industry does not automatically adopt improved equipment and procedures as rapidly as they are developed in the laboratory. Too frequently, we who are responsible for the laboratory research and testing do not keep as closely in touch with practical operations in mines and plants as we should to have the right balance between theory and practice. In our future research we should make every effort to maintain close contact between research and operating staffs. If this is done, we may feel assured that the real achievements of mine-safety research will be shown in a gratifying record of decreasing casualties in our mines and mineral industries.

ACKNOWLEDGMENTS

Grateful acknowledgment is made for collaboration in the preparation of this paper to the following members of the staff of the Central Experiment Station of the Bureau of Mines, Pittsburgh, Pa.:

Lawrence B. Berger, Acting Chief, Health Branch.
Glenn H. Damon, Supervising Engineer, Explosives Testing Section.
Ernest J. Gleim, Supervising Engineer, Electrical-Mechanical Section.
Irving Hartmann, Supervising Physicist, Experimental Coal Mine and Dust Explosions Section.
George W. Jones, Supervising Chemist, Gas Explosions Section.
George E. McElroy, Supervising Engineer, Mine Ventilation Section.
Seldon J. Pearce, Chemist, Health Branch.
W. Dan Walker, Jr., Chief, Pittsburgh Branch, Accident Prevention and Health Division, Region VIII.
Edward Thomas, Chief, Roof Control Section, Health and Safety Division, Washington, D. C.

Generated on 2024-09-19 22:17 GMT / https://hdl.handle.net/2027/osu.32435030643720
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from THE OHIO STATE UNIVERSITY